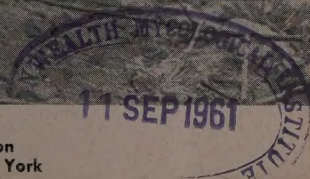
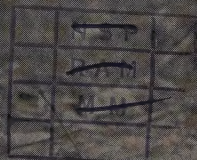


BULLETIN 958

AUGUST 1960

Studies on Cold Hardiness of Peach Trees

LOUIS J. EDGERTON



Cornell University Agricultural Experiment Station
New York State College of Agriculture, Ithaca, New York

Contents

Methods	4
Experimental orchards	4
Freezing equipment and procedure	5
Evaluation of hardiness	6
Results	8
Cold hardiness of flower buds	8
Changes in hardiness from fall until spring	8
Comparative fluctuation during rest period and dormancy.....	10
Periods of maximum hardiness	14
Conditions that result in bud killing	15
Effect of chemical thinning on bud hardiness	16
Effect of nitrogen and cultural practices	16
Bud hardiness of different varieties	18
Cold hardiness of woody tissues	19
Increase in hardiness in the fall	19
Effect of pruning on wood hardiness	21
Effect of chemical thinning on wood hardiness.....	23
Effect of fertilization and cultural treatments	23
Discussion	25
Development of hardiness in various tissues	25
Orchard practices that contribute to maximum hardiness	27
Summary	28
Literature cited	29

Studies on Cold Hardiness of Peach Trees

Louis J. Edgerton*

Winter injury is a serious problem for peach growers in New York. The peach does not develop as much cold hardiness as most of the other deciduous fruits. While some splendid opportunities for growing peaches can be found in this state, where favorable soils and ready markets exist, certain characteristics of the climate involve the danger of winter injury to the buds and wood of this relatively tender species.

The original home of the peach, according to Hedrick (1917), is the warm, sunlit region of Mid-Asia. There it is not subjected to the extremes of temperature and climate that prevail in many parts of the United States where it is grown. When the cultivation of any plant is undertaken outside the limits of its natural habitat, occasional injury and loss from adverse weather conditions are to be expected.

The prevalence and seriousness of winter injury in this section of the country are indicated in the two following quotations. Havis and Lewis (1938), in reporting on severe

winters in Ohio, state: "There were, of course, other winters than the 18 described as severe for fruit trees in which trees in certain parts of the state were badly injured. . . . In fact it is an unusual year in which no winter injury occurs in Ohio". Also, Bradford and Cardinell (1926) reported as follows: "Since 1845 there have been ten winters (in Michigan) outstanding for the amount of damage to fruit trees, a little more than one for each decade. Many other winters have brought extensive and severe damage and there is hardly one in the 80 to which some specific instances of damage cannot be assigned". Often the damage and injury from low temperature is not evident immediately but may continue to appear for several years.

In what forms may this injury appear in peach trees and how can the grower recognize them? What are the climatic and cultural conditions that influence the susceptibility to injury? And what can the grower do to minimize injury and loss from low temperatures? These and similar questions are frequently raised by growers. It is the purpose of this bulletin to try to answer

*Professor, Department of Pomology, New York State College of Agriculture at Cornell University, Ithaca, N. Y.

some of them. The data presented are based on studies conducted by the department since 1946.

The location of the orchard with respect to climatic conditions, site, and soil are directly related to winter injury. Orchards located where winter temperatures below -10°F . occur frequently are more

likely to suffer. Also, the air drainage and soil conditions of the site can influence the extent of winter injury and permanence of the planting. These topics are discussed in Cornell Extension Bulletin 869 and will not be dealt with specifically in this publication.

Methods

Experimental orchards

The majority of these studies on cold hardiness were carried out on material collected from the Cornell University orchard near Ithaca. Several different varieties were used in the course of the investigation including Golden Jubilee, Hale-haven, and Elberta. The trees were located in two different blocks, one planted in 1942, and the other in 1950. Samples were collected from the older block for freezing studies until 1955. During the winter of 1955-56 and thereafter, most of the samples were collected from trees of the same varieties in the younger orchard. These two blocks were located at approximately the same elevation, and soil type and drainage were similar. The cultural practices, consisting of cultivation from early spring until midsummer followed by the seeding of an overwintering cover crop, were the same in both orchards. The trees received moderate annual application of nitrogen.

Hardiness studies were also conducted on peach trees and buds located in orchards at Geneva, in western New York, and in the Hud-

son Valley during this period. Data will be presented from some of these studies as they pertain to the effects of cultural practices, fertilization, and thinning on cold hardiness. A brief description of the

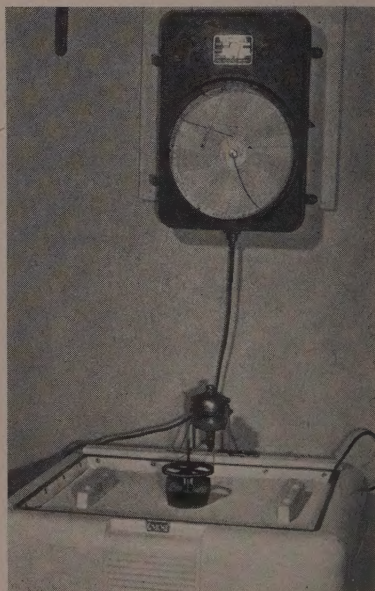


Figure 1. Apparatus used for controlled-freezing studies on peach buds and wood.

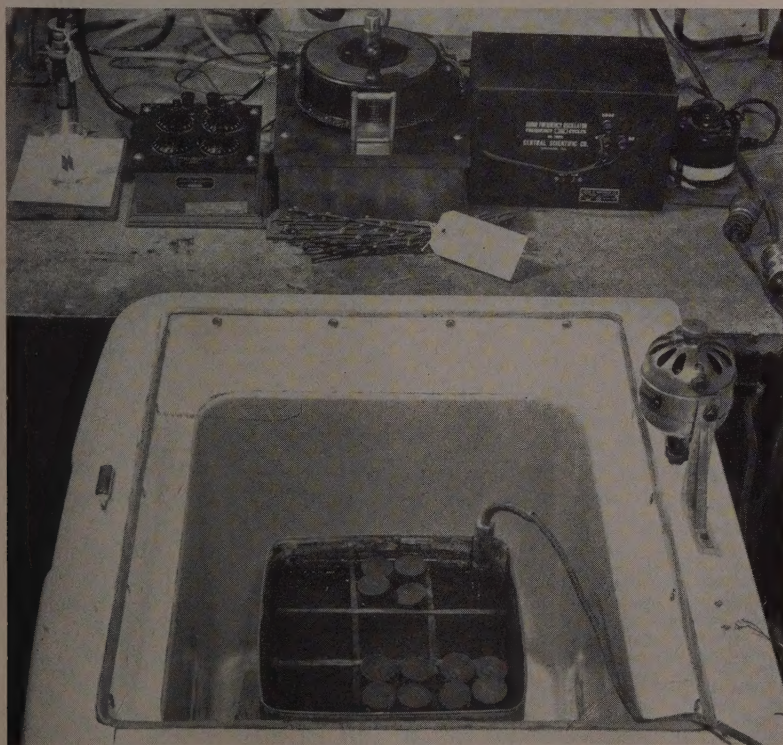
respective orchards will be given with the presentation and discussion of the data.

Freezing equipment and procedure

The cold hardness determinations on the fruit buds were made by the controlled, direct-freezing method, using a deep-freeze cabinet modified for this work (figs. 1 and 2). By this procedure, glass tubes containing the twig samples are

placed in a tank of anti-freeze solution within the freezing compartment. The temperature of the anti-freeze solution is then lowered at approximately 2°F. per hour with constant agitation until the desired minimum temperature is reached. The samples are held at this temperature about 30 minutes, then they are removed from the freezer and allowed to thaw at room temperature. An evaluation of this

Figure 2. Interior of freezing chamber. Peach twigs or other tissues to be frozen are placed in stoppered tubes and immersed in antifreeze solution. Conductivity equipment is shown on table.



method of determining bud hardiness has been reported by Meader *et al.* (1945). A sufficient number of twigs was collected from each variety or plot to make up composite samples of about 200 buds for each freezing temperature employed. Samples were usually removed from the freezer over a range of at least three or four temperatures to get a spread in the proportion of the buds killed and of injury to the woody tissues.

Evaluation of hardiness

In the studies on bud hardiness, the record of injury at a given temperature was made by counting the dead and uninjured buds on the twigs in a given sample (fig. 3). Injury was ascertained by cutting the buds transversely with a razor blade to examine the inner part. This was done usually the day after the twigs were removed from the freezer.

In some of the accompanying tables the actual survival percentages of samples at various temperatures are recorded. However, in the charts that show changes in cold hardiness of Halehaven buds during several winters at Ithaca, the temperature required to kill 50 percent of the buds at each sampling date has been determined from the survival data at the various temperatures. An example is shown in figure 4. Here the actual hardiness data for the temperatures used on 3 dates are plotted. The temperature required to kill 50 percent of the buds can then be determined from such curves. This point is used as a convenient means of



Figure 3. Section through flower buds of peach, showing dark, discolored flower parts in a bud killed by low temperature (left) and an uninjured bud (right).

plotting the fluctuation in cold hardiness through successive seasons, and is referred to as the "hardiness index". A similar evaluation was suggested by Proebsting and Fogle (1956), and the term "T 50" was used to identify this theoretical temperature. On the basis of the curves shown in figure 4 and of similar data from a large number of tests, it is apparent that practically all buds will be killed at a

temperature from 2 to 4 degrees below the temperature that kills 50 percent of the buds. The actual temperature spread between these two levels of injury depends upon the time of year, stage of bud development, and other factors.

Samples were collected for this phase of the study at intervals of about one to two weeks from late fall until spring. The usual sequence of collections was changed occasionally to follow a temperature trend or weather pattern more closely. Sampling was discontinued in a few winters, as shown in the accompanying charts, when a sharp freeze in the orchard killed a large proportion of the buds. A single line showing mean daily temperatures was used in the charts in preference to recording both the daily maximum and minimum temperatures. An examination of charts

for several winters, on which the hardiness index was plotted with the maximum and minimum daily temperatures and the mean, showed that changes in hardiness follow the mean more closely than they do either the maximum or minimum alone. Also the temperature trends are easier to follow with a single line where daily values are used than where both maximum and minimum values are plotted.

The determination of injury in the woody tissues of peach twigs or other tree parts was done by electrical conductivity measurements. The thawed twigs were cut into $\frac{1}{2}$ -inch lengths, weighed, and placed in flasks. Distilled water was added at the rate of 5 times the weight of the twig sample. The flasks were covered and left for 18 hours at room temperature. At the end of the diffusion period, con-

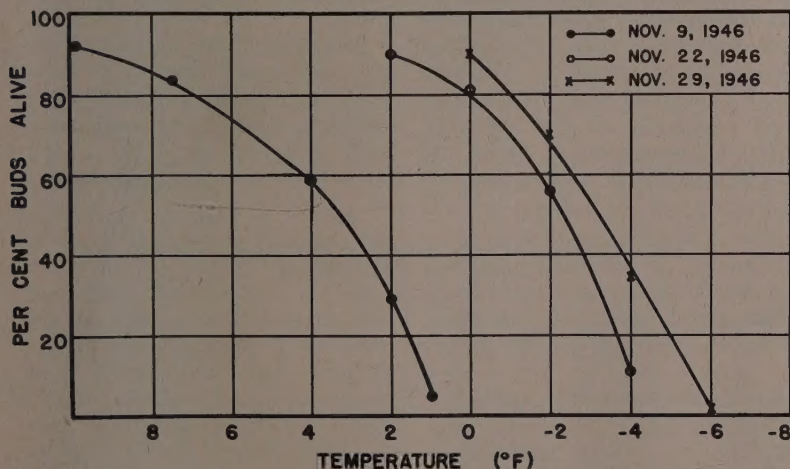


Figure 4. Survival of Halehaven flower buds collected on 3 dates in fall of 1946 and frozen at several temperatures. Hardiness index or temperature required to kill 50 percent of buds can be determined from such curves.

ductivity readings were made with appropriate equipment on the solutions at 77°F. (fig. 2). As demonstrated by Dexter *et al.* (1932) and Stuart (1938) the more severely injured the tissue, the greater the amount of electrolytes it releases,

and the solutions bathing these frozen samples thus have conductance values in relation to the degree of injury. Microscopic examination was also made of many of the frozen samples to determine the location and extent of injured tissue.

Results

Cold hardness of flower buds

The results of studies concerned with fluctuations in cold hardness of flower buds are presented first, because these investigations comprised the initial part of the work and because it has been possible to obtain rather complete data on bud hardness through a number of successive seasons.

Changes in hardness from fall until spring. Peach flower buds attain remarkable cold hardness during the late summer and early fall, even before cold temperatures prevail. For example, in 1947 the first twigs were collected for hardness studies on September 18. On that date practically all the buds survived a temperature of 20°F., and it required 18°F. to kill approxi-

mately one-half of the buds (table 1). With the cooler weather of late September and early October, the buds developed additional resistance and had attained a hardness index of 12°F. by October 3. For the next 3 weeks, little or no increase in bud hardness occurred during a period when mild weather prevailed (table 1 and fig. 5). With the return of cooler weather in late October and November, rapid increase in bud hardness again took place.

Maximum hardness was attained by mid-January, after an extended period of continuously cold weather (illustrated by the curve for mean daily temperatures in fig. 5). Unfortunately, a low temperature of

Table 1. Changes in cold hardness of Halehaven peach buds, Ithaca, New York—1947-48

Date sampled	Temp.* frozen		Date sampled	Temp. frozen	
	Degrees F.	Percent		Degrees F.	Percent
Sept. 18.	18	58.8	Nov. 21.	- 4	65.3
Sept. 26.	14	50.3	Nov. 28.	- 7	63.0
Oct. 3.	12	52.9	Dec. 12.	-10	51.4
Oct. 10.	12	69.6	Dec. 26.	-12	40.0
Oct. 17.	12	58.2	Jan. 2.	-12	84.5
Oct. 23.	12	42.2	Jan. 8.	-12	89.2
Nov. 7.	9	43.4	Jan. 17.	-15	57.1

*These temperatures were selected from among the range used for each sampling date as being those giving bud survival near the 50 percent figure, with the exception of January 2 and 8.

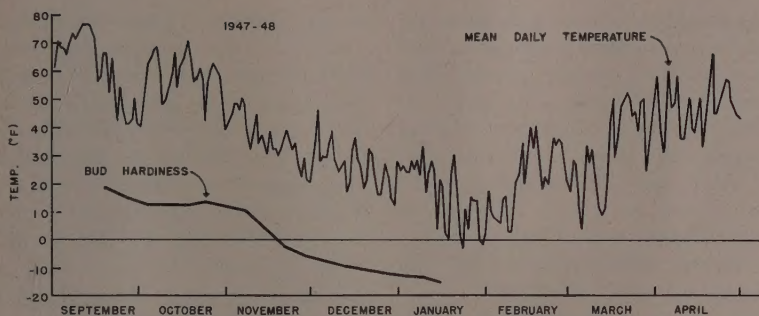


Figure 5. Cold hardiness of Halehaven flower buds during 1947-48 at Ithaca, New York. Line marked "bud hardness" shows temperature required to kill 50 percent of buds.

-19°F. on January 19 killed all, or a large proportion, of the buds on most varieties. Consequently, collections for artificial freezing were discontinued for that winter. It is interesting to note, however, that on January 17, two days before this hard freeze, buds collected for hardiness determinations exhibited marked cold resistance with more than 50 percent of the buds surviving -15°F.

These data also illustrate the validity of the experimental procedure for cold-hardiness determination of the buds. A moderate freeze occurred on January 15, with a low temperature of -12°F. recorded at the orchard. A sample collected the following day and examined for bud injury revealed that about 3 percent of the buds had been killed at that time. The experimental freeze of the previous week (January 8) had indicated that the buds were quite hardy, with nearly 90 percent of the buds surviving the freezer temperature of -12°F.

Changes in bud hardiness through the winter and early spring

can be seen in the charts for other years where no extensive bud loss occurred. It will be noted that during a typical winter such as 1946-47 (fig. 6), increases in bud hardiness are associated with periods of cold daily mean temperatures, and losses in hardiness are associated with periods of rising daily mean temperatures, particularly after the first of January. Continued warm weather after the first of April, 1947, resulted in bud activity and loss in cold hardiness until the buds were fully opened, with the trees in bloom on May 13. At this point a temperature of 25°F. killed approximately 50 percent of the flowers. These fluctuations in hardiness as influenced by orchard temperature conditions have been reported by Scott and Cullinan (1946) and Chaplin (1948) for similar controlled-freezing studies.

During midwinter and up until the time the buds had swollen to the extent of showing an occasional trace of pink, on about April 30, 1947, the entire flower primordia was killed at a temperature that

caused injury to any part of it (as illustrated in fig. 3). However, with further development of the bud and at full bloom, the pistil or ovary was often killed at a marginal temperature that caused no injury to other parts of the flower. Such injury was, of course, recorded as a dead flower when hardiness determinations were continued through the spring until bloom.

Comparative fluctuations during rest period and dormancy. Buds of peach and other deciduous tree fruits have a rest period, starting in late summer after bud formation and continuing into winter. During this period the bud does not become active even though the temperature may be warm enough for growth. After sufficient exposure to cold temperatures, or "chilling" in fall and early winter, the rest period is broken and the bud may then respond to periods of warm weather, culminating in rapid development and full bloom during the warm weather of spring. During short periods of mild weather from midwinter until early spring, there may be a rapid loss in hardiness even though no activity of the bud is visible. This is illustrated by the curve depicting bud hardiness in the accompanying charts (figs. 6, 7, and 8). Peach growers are usually apprehensive during this period when a few warm days are followed by a sudden drop in temperature.

The extent of hardiness fluctuations associated with temperature changes in late fall and early winter, when the buds are still in the rest period, has not been investigated as extensively as have changes later

in the dormant season. A detailed study of these changes has been reported previously by the author (Edgerton, 1954). During the course of study of changes in bud hardiness it has been possible to make some interesting comparisons between fluctuations in bud hardiness during and following the rest period.

By examining the curves for bud hardiness in the accompanying charts, it will be noted that short periods of warm weather from the beginning of the sampling period until about the end of December result in no loss in bud hardiness. Exceptions to this can be found in the charts for 1947, 1948, 1951, 1952, and 1953, shown in figures 5, 6, 7, and 8. During these years, prolonged periods of 6 or 7 days occurred during which the daily mean was 35°F. or above, resulting in slight loss in hardiness. The hardiness data for bud samples collected from the orchard from October 29 to December 7, 1951, are given in table 2.

Buds frozen December 7, after 7 days with a daily mean temperature of 47°F., were less hardy than similar buds were on November 30. This is true for 3 varieties from which twig samples were collected for hardiness tests during this period. This slight loss in hardiness, requiring about 7 days of mild weather, is in contrast to the rapid loss in hardiness which occurs with the advent of a brief warm period after the rest period is over.

In some other tests on changes in bud hardiness during the rest period, a large sample of twigs were collected in the late fall, brought

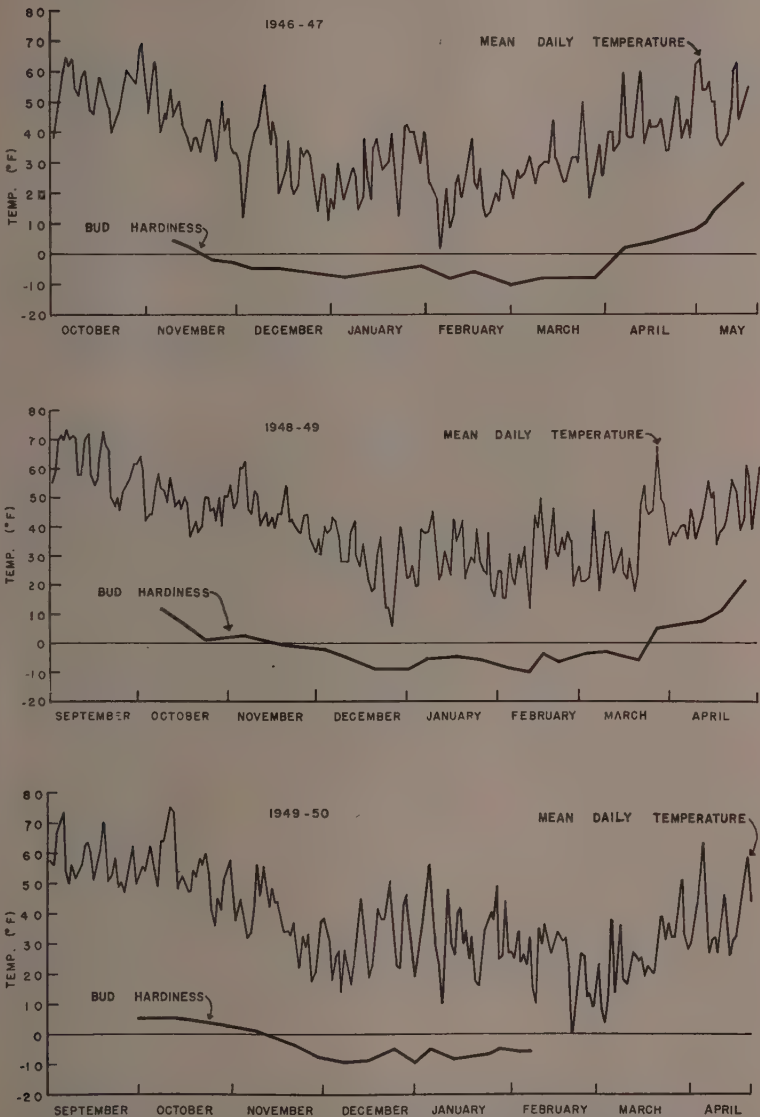


Figure 6. Cold hardiness of Halehaven flower buds during 3 winters: *top*, 1946-47; *center*, 1948-49; *bottom*, 1949-50; at Ithaca, New York. Buds were in pink stage May 3, and full bloom May 13, 1947; buds were in pink stage April 25, and full bloom May 1, 1949.

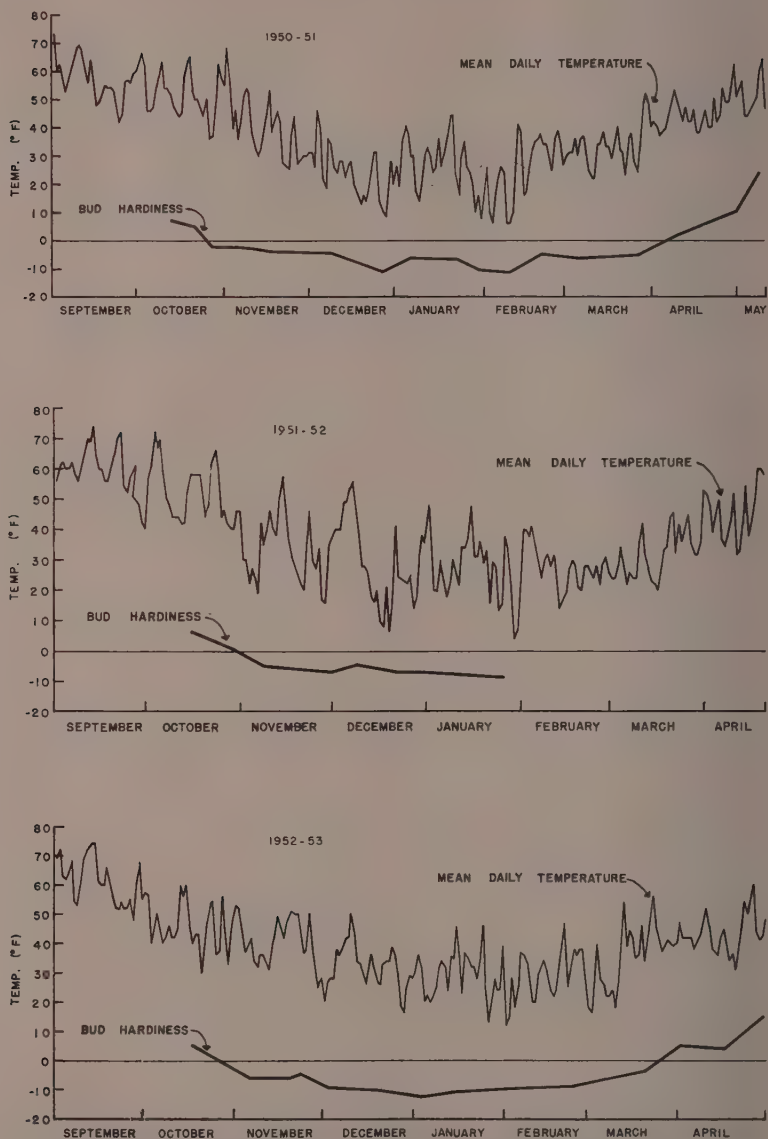


Figure 7. Cold hardiness of Halehaven flower buds during 3 winters: top, 1950-51; center, 1951-52; bottom, 1952-53; at Ithaca, New York. Buds were in pink stage April 30 and full bloom May 8, 1953.

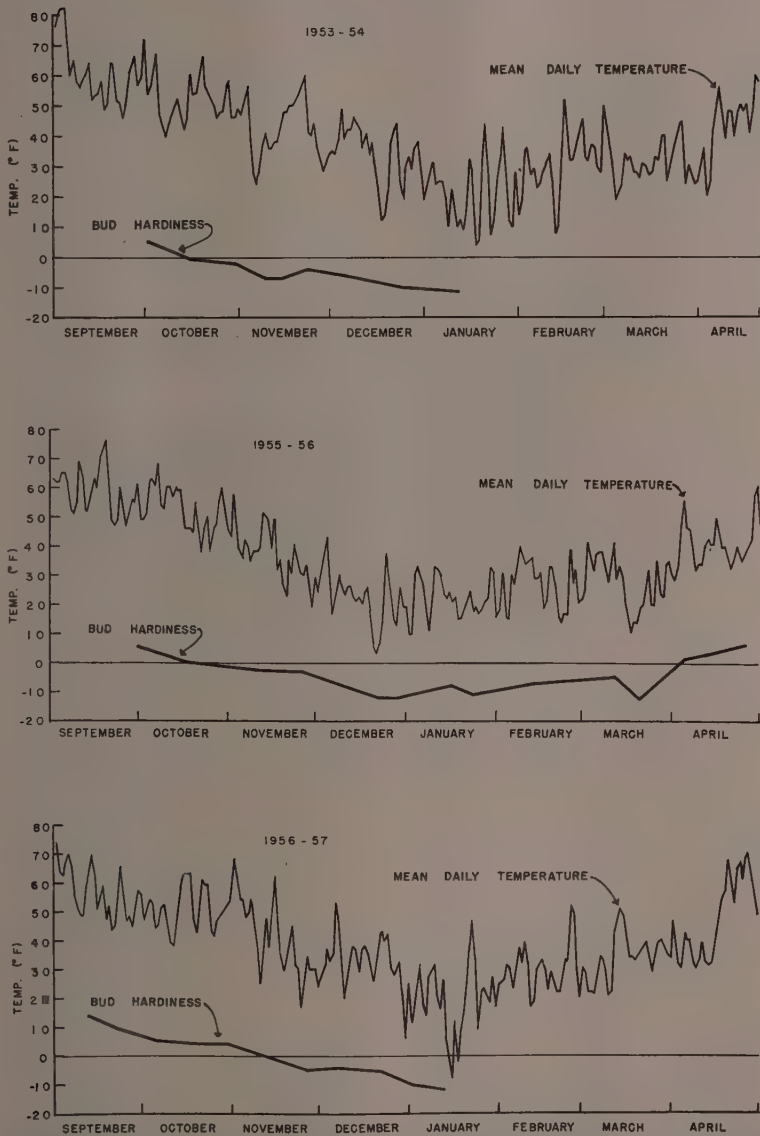


Figure 8. Cold hardiness of Halehaven flower buds during 3 winters: top, 1953-54; center, 1955-56; bottom, 1956-57; at Ithaca, New York. Buds were in pink stage May 10 and full bloom May 16, 1956.

Table 2. Influence of temperature fluctuation during fall of 1951 on hardiness of peach flower buds, Ithaca, New York*

Date collected 1951	Mean daily temperature†			Buds alive:					
	3 days	7 days	Normal	Halehaven frozen at:		Golden Jubilee frozen at:		Elberta frozen at:	
				-4° F.	-8° F.	-4° F.	-8° F.	-4° F.	-8° F.
				Degrees F.			Percent		
Oct. 29....	41	48	47	23.3	—	45.8	—	31.7	—
Nov. 8....	32	29	43	67.4	1.9	75.4	16.3	69.4	2.7
Nov. 30....	23	28	34	85.2	32.8	95.7	40.7	82.9	26.2
Dec. 7....	53	47	32	51.7	3.4	78.1	6.9	72.1	4.4

*Adapted from table 4, Amer. Soc. Hort. Sci. Proc. 64:178. 1954.

†Mean temperatures for 3-day and 7-day periods before indicated sampling date. Normal mean is for 7-day period before date.

to the laboratory, and stored at different temperatures. Samples from these storage lots were frozen periodically to determine loss in hardiness, if any, as compared with hardiness at the time they were collected. No loss in hardiness was detected after 2 and 4 days storage at 65°F. The twigs, of course, were held during this period in a suitable container to avoid loss of moisture and to keep them fresh.

After 7 days at this temperature, however, some loss in hardiness was detected. In contrast to this, similar samples held at 32°F. maintained or slightly increased their cold resistance during the 7-day period. A similar storage test was conducted in February of the same season, when the buds were out of the rest period. The samples were collected from the same trees. At this time a significant loss in hardiness occurred after 2 days storage at 65°F. A similar loss in hardiness following short periods of mild weather after midwinter can be seen in most of the charts.

Periods of maximum hardiness.

An inspection of the charts showing the hardiness index of Halehaven buds during 10 seasons (figs. 5, 6, 7, and 8) reveals the fact that the temperature at which 50 percent of the buds can be killed dips to about -10°F. at one or more times each winter. That this point is usually reached for the first time by the latter part of December probably accounts for the claims of some authors that maximum bud hardiness occurs in the winter near the end of the rest period. However, a further inspection of the charts shows that maximum hardiness may develop later in the winter or even in early spring after some loss in hardiness has occurred. It will be seen that this loss and subsequent gain in hardiness is brought about by changes in the daily mean temperature. For example, on March 20, 1956, a temperature of -10.5°F. was necessary for 50 percent kill of Halehaven buds. This is approximately the same degree of hardiness as the buds had attained in late

December of that season, and resulted from a cooling trend of about 1 week, during which the daily mean temperatures were 30°F. or below.

Periods of extreme hardiness were detected in a few instances during the course of this study in which Halehaven buds resisted temperatures appreciably below -10°F. One such instance in the 1947-48 season has already been cited on page 9, and is shown in figure 5. Flower buds of other varieties were also unusually hardy at that time (table 3.) This unique cold resistance developed as the result of an extended period of cold weather from late December to mid-January, during which the minimum temperature did not dip low enough to cause injury. Figure 5 shows that temperature conditions during the late fall of that year were not

particularly conducive to development of hardiness. In fact, the hardiness index was above 10°F. until about November 7, whereas in most years it was at 0°F. or below by this time. Likewise, growing conditions during the summer of 1947 were normal in so far as light intensity and rainfall were concerned, and the trees had produced a good crop of fruit that summer. It is apparent, therefore, that this extreme hardiness developed in response to prolonged cold weather just before the freeze.

In 1956-57 flower buds of this variety again developed somewhat more hardiness by January 12 than in the average winter. Samples collected on January 12 had a hardiness index of -12.5°F. Unfortunately, a sharp freeze occurred during the next few days with temperatures of -18°F. on January 14 and -25°F. on January 15 recorded at the orchard, so that further appraisal of bud hardiness for this period was not possible.

Conditions that result in bud killing. During the two winters referred to above, 1947-48 and 1956-57, most or all of the buds on peach varieties at Ithaca were killed by extremely low temperatures. In several other winters, less severe temperatures caused substantial losses because they occurred at a time when the buds were not so hardy. For example, a low temperature of -10°F. at Ithaca on January 30, 1952 killed about three-fourths of the Halehaven buds. The hardiness index for this variety had been from about -8° to -9°F. through most of January because

Table 3. Survival of flower buds of several peach varieties after exposure to low orchard temperatures during 2 winters, Ithaca, New York

Variety	Buds alive*	
	Feb. 19, 1948	Feb. 13, 1950
	Percent	
Oriole.....	42.5	55.0
Veteran.....	21.6	49.6
Carman.....	21.5	14.5
Belle of Georgia.....	19.4	28.1
Valiant.....	18.9	14.6
Halehaven.....	16.8	14.8
Golden Jubilee.....	14.9	10.2
Cumberland.....	12.3	12.0
Raritan Rose.....	10.7	45.1
Elberta.....	8.9	4.1
J. H. Hale.....	2.0	1.5

*Survival data obtained on dates indicated by examining from 200 to 300 buds of each variety. Injury as observed on February 19, 1948 resulted from low temperatures of -19° F. on January 19 and -20° F. on February 1. Injury as observed February 13, 1950, resulted from low temperature of -8° F. on February 8, 1950.

of occasional warm periods and fluctuating temperatures. Thus, the drop in temperature to -10°F . killed many of the buds, and it was not feasible to continue hardiness tests with that variety through the remainder of the winter.

Substantial injury to peach buds also occurred in 1949-50 when a drop in temperature to -8°F . on February 8 caught the buds after a few days of mild weather and killed about 90 percent of the Halehaven buds. An examination of the chart in figure 6 shows the marked fluctuation that occurred in bud hardiness from late December until mid-February of that winter when this freeze occurred. Survival data for other varieties following this February freeze are shown in table 3.

Loss of peach buds occurred in a similar manner in other winters. In 7 of the 10 years for which data are reported here, some injury to peach buds occurred before bloom time. Buds of all varieties were completely killed only once. It is also of interest to note that only once, from the time this work was started in 1946 until the present, were flower buds killed under orchard conditions before the first of January. This happened in December, 1958. A low temperature of -9.5°F ., on December 11 that year, killed approximately 20 percent of the Halehaven buds. The buds were still in the rest period at that time but had been slow in developing hardiness because of cloudy, wet weather during September and October. Also, Novem-

ber was characterized by somewhat milder weather than normal.

Effect of chemical thinning on bud hardiness. The effects of a number of orchard practices on cold hardiness of peach flower buds have been investigated during this study. These have included hand and chemical thinning, cultivation, fertilization, and time and severity of pruning. Of all these practices the one that has had the most consistent and marked effect on bud hardiness is chemical thinning. This was first observed in connection with some freezing studies in 1946-47, and again under orchard conditions in 1947-48, when low temperatures occurred in a Hudson Valley orchard where chemical thinning tests had been conducted on certain trees the previous summer (Edgerton, 1948). More detailed cold-hardiness tests have been conducted in subsequent years by collecting twigs from trees thinned to various degrees and at various times after bloom (Edgerton and Hoffman, 1952). Both blossom thinning with dinitro sprays and post-bloom thinning with growth regulators such as naphthyl phthalamic acid and naphthaleneacetic acid, where effective reduction in fruit set was accomplished, have resulted in increased bud hardiness the following winter (tables 4 and 5).

Effect of nitrogen and cultural practices. The cold hardiness of peach flower buds is not affected as markedly by differences in the nitrogen level of the tree as might be expected. An extensive test on

Table 4. Peach fruit bud hardness as affected by chemical thinning, Niagara County, New York. (Twigs collected for freezing January 31, 1953)

Variety	Thinning treatment* (1952)	Blossoms setting fruit 7/21/52	Flower buds alive at:	
			-7° F.	-10° F.
			Percent	
Halehaven.....	Amide 60 p.p.m. June 10	13.0	59.3	2.2
	NAA 30 p.p.m. June 10	5.0	69.5	14.3
	Check	35.0	47.3	1.8
Elberta.....	Amide 50 p.p.m. June 10	17.0	62.2	5.1
	NAA 15 p.p.m. June 10	16.0	55.9	5.6
	Check	26.0	42.3	0

*Amide = Naphthaleneacetamide; NAA = Naphthaleneacetic acid. These materials were applied approximately 30 days after full bloom.

Table 5. Peach fruit bud hardness as affected by chemical thinning, Wayne County, New York. (Twigs collected for freezing February 8, 1956)

Variety	Thinning treatment* (1955)	Blossoms setting fruit 6/30/55	Flower buds alive -8° F.
			Percent
Redhaven.....	NPA 200 p.p.m. May 7	18.2	29.6
	NPA 300 p.p.m. May 7	13.3	32.8
	Check	27.5	7.2
Elberta.....	NPA 100 p.p.m. May 7	21.6	43.4
	NPA 200 p.p.m. May 7	9.7	63.2
	Check	25.2	13.8

*NPA = Naphthyl phthalamic acid applied at concentrations indicated on May 7, approximately 3 days after full bloom.

the effect of nitrogen fertilization and cultivation of peach trees was carried on in Monroe County over a period of several years. It was found that within a range of leaf nitrogen of about 2.2 to 3.8 percent in midsummer, which was obtained with these treatments, there was little effect on bud hardness. Further work since that publication (Edgerton and Harris, 1950) has confirmed the earlier results. For example, in December of 1949-50 it was possible to measure the comparative cold hardness of buds from the different treatments in this orchard by the controlled-freezing technique, and again later in the season, to evaluate the effect

of the treatments on cold hardness when a hard freeze in the orchard on February 8 killed about one-half of the buds. These results are shown in table 6. Although these differences in bud survival are not large, there is an indication that buds from the high-nitrogen trees are somewhat less hardy in midwinter than buds from trees with a lower nitrogen level. Apparently other tree responses to those treatments such as yield, color, maturity date, and fruit quality are more important practical considerations than bud hardness (Harris and Boynton, 1952). Of course, buds on trees that are weak and devitalized from nitrogen deficiency are not likely to

Table 6. Effect of nitrogen and cultural treatment on cold hardiness of Elberta peach flower buds, Monroe County, New York, 1949-50*

Date sampled	Temperature frozen	Buds alive:			
		LR	LC	HR	HC
	Degrees F.	Percent			
Dec. 14, 1949.....	-8.5	63.2	57.7	45.6	49.3
Feb. 13, 1950†.....	-9.0†	73.0	69.0	58.6	59.5

*Twigs collected on dates indicated from trees in various plots. Treatments were as follows: LR=low nitrogen (0.5 lb./tree) with rye grass cover; LC=low nitrogen (0.5 lb./tree) with clean cultivation; HR=high nitrogen (1.0 lb./tree) with rye grass cover; HC=high nitrogen (1.0 lb./tree) with clean cultivation. In 1949 plots LC and HC received "irashy" cultivation instead of clean cultivation until June 20.

†Twigs were collected from various plots on this date for examination and determination of injury resulting from low temperatures of -9° F. on February 8.

develop maximum hardiness. This is also true with trees weakened from other causes such as improper soil, poor soil drainage, borer infestation, and winter injury to the trunk or main limbs. Likewise, the wood and buds of trees making excessive vegetative growth are slow to mature in the fall, and these trees may not develop as much resistance to low temperature as do those making moderate growth. But within these extremes the influence of nitrogen level or cultural practice on bud hardiness is not marked.

In another experiment in Niagara County it was possible to compare the effect of cultivation with that of a permanent cover crop on cold hardiness of peach fruit buds. In the cultivated plots the soil was worked until early July, whereas the other plots had been maintained under two types of permanent covers for the previous year. The data, as shown in table 7, indicate that, under these conditions, the cultural treatment had little or no effect on the bud hardiness of healthy, vigorous trees on good soil. It is also interesting

to note that the Jubilee buds were considerably hardier than the Elberta buds.

Some recent studies have been conducted on the effect of time and severity of pruning on bud hardiness. No significant differences in the effect of pruning severity on bud hardiness are apparent from the early results in this study. More pronounced effects of pruning severity are apparent on yield, fruit size, color, and maturity date than on bud hardiness. A detailed report on this project will appear in a later publication.

Some tests have been conducted on the effect of early winter pruning on cold hardiness of peach trees. The major emphasis has been to determine the effect of this pruning on wood hardiness rather than bud hardiness. This will be discussed in the following section.

Bud hardiness of different varieties. Most of the routine work on fluctuations in bud hardiness through the winter has been conducted on the Halehaven, Jubilee, and Elberta varieties. The relative bud hardiness of these varieties is shown in some of the tables. Twigs

Table 7. Effect of cultural treatment on cold hardiness of peach flower buds, Niagara County, New York. (Twigs collected for freezing study March 12, 1953)

Variety and treatment	Buds alive at:			
	-3° F.	-5° F.	-7° F.	-9° F.
	Percent			
Golden Jubilee				
Cultivated to 7/2/52.....	—	55.1	11.8	0
Broome grass cover.....	—	50.7	11.8	0
Elberta				
Cultivated to 7/2/52.....	46.8	27.1	—	—
Vetch cover.....	52.4	22.6	—	—

from other varieties have been frozen occasionally, and in a few instances during this period (1948 and 1950) an orchard freeze has killed some peach buds of all varieties. On such occasions it has been possible to examine for survival buds from a large number of varieties in the orchard. Table 3 lists the varieties with bud survival for these two winters.

Cold hardiness of woody tissues

Increase in hardiness in the fall.

Unlike the fruit buds, which develop considerable hardiness in the early fall, twigs and bark of peach trees are often slow to harden. Twigs collected and frozen for bud-hardiness studies in the fall invariably show injury in the bark, cambium, sapwood, and even bud scales, at temperatures that result in little or no injury to the flower primordia. Usually this situation is equalized by early December, with the buds and the woody parts reaching a state of comparable hardiness. From that time on provided that the cold weather continues, the stem tissues, particularly the cambium and bark, usually go

on to develop more cold resistance than that attained by the buds. Data presented in table 8 show these changes in comparative hardiness during the late summer and fall of 1957, when periodic collections

Table 8. Relative cold hardiness of peach twigs and flower buds as determined by controlled freezing in late summer and fall, 1957, Ithaca, New York

Date and variety	Temp. frozen	Twig conductivity*	Buds killed
	Degrees F.	Micromhos†	Percent
Aug. 27, 1957			
Jubilee....	20	88.6	0
Halehaven....	20	116.4	0
Elberta....	20	130.7	0
Sept. 19, 1957			
Jubilee....	17	112.9	2.8
Halehaven....	17	119.2	0
Elberta....	17	135.8	9.8
Oct. 15, 1957			
Jubilee....	7	89.2	0
Halehaven....	7	87.7	0
Elberta....	7	93.7	1.4
Nov. 14, 1957			
Jubilee....	-5	53.8	17.8
Halehaven....	-5	50.5	29.0
Elberta....	-5	49.0	50.0
Dec. 15, 1957			
Jubilee....	-11	6.8	85.9
Halehaven....	-11	1.0	61.8
Elberta....	-11	9.6	90.9

*Values presented in table are differences between conductivity of a check or unfrozen sample and a similar sample frozen at indicated temperature. Higher values represent greater injury to tissues.

†A unit of conductance equivalent to mho $\times 10^{-6}$

were made for this purpose. The last tissues to develop cold hardiness and maturity during the fall are the bark and cambium of the trunk and crotches of main limbs. During the fall, hardiness develops first in the sapwood of the twigs and branches, then in the trunk and main crotches. On the trunk, the area from the ground level to a few inches above the ground is especially sensitive to freezing injury during the late fall and early winter, when sharp freezes are occasionally experienced (fig. 9). This is sometimes referred to as crown injury. The bark tissues in narrow-angled crotches are also more susceptible than similar tissues

in wide-angled crotches, particularly where these narrow crotches occur near the ground (fig. 10).

Experimental evaluation of the hardiness of the thick bark tissues of the trunk has been less successful than similar work with the twigs because of the nature of the tissues and the difficulty of collecting samples of bark and freezing them under controlled conditions. However, there is ample field observation regarding the susceptibility of this tissue to freezing injury in fall and early winter. What makes this form of injury especially serious is that the cambium is often killed. With the loss of this vital meristematic tissue, no new conducting

Figure 9. Injury from low temperature to inner bark, cambium, and sapwood of peach tree, late fall 1942, Niagara County, New York. (Photographed spring, 1943.)





Figure 10. Injury to bark in the narrow-angled crotches of Libertia peach tree, Geneva, New York. (Photographed spring, 1946.)

tissue can be laid down the following season to replace the damaged parts.

Effect of pruning on wood hardness. In 1956-57 a test was conducted on the effect of early winter

pruning on tree hardiness. Orchard observations with both peach and apple have indicated that trees pruned before a hard freeze are more susceptible to injury than similar trees not pruned before a freeze. On December 21, 1956, 4 Elberta trees and 4 Halehaven trees in the department orchard were given a conventional pruning, consisting of heading back into 2- and 3-year-old wood and some thinning out. These trees were randomized with 4 similar trees of each variety that were left unpruned. Twig samples were collected from these trees on January 7, 1957, for freezing studies. The data in table 9 show that twigs from the unpruned trees were slightly harder than similar twigs from the trees pruned on December 21. In some further tests it was apparent that twigs and bark tissues near the pruning cuts were affected more than twigs selected at the tips of branches at some distance from a pruning cut. This effect was also demonstrated by Edgerton and Shaulis (1953) in some studies on hardiness of grape canes.

Table 9. Effect of early winter pruning on cold hardiness of peach twigs, Ithaca, New York, 1956-57. (Twigs collected for freezing January 7, 1957)

Variety and treatment	Conductivity	
	Not frozen	Frozen at -17° F.
	Micromhos	
Halehaven		
Pruned Dec. 21, 1956	119.8	204.3
Not pruned.	115.3	185.8
Elberta		
Pruned Dec. 21, 1956	112.1	189.3
Not pruned.	118.4	163.1

As mentioned in the discussion of bud hardiness, the lowest temperatures in recent years were experienced in Ithaca in January, 1957, with a minimum of -24.5°F. recorded on January 15. This gave an ideal opportunity not only to observe the effect of pruning before a freeze on susceptibility to injury under orchard conditions but also to make a comparison with the controlled freezing tests conducted a week earlier. Examination of bark and wood samples from these trees after the freeze revealed extensive injury in the bark, cambium, and sapwood of the pruned trees. At these low temperatures some injury also occurred in the sapwood of the main branches and in the bark in narrow crotches of the unpruned trees, but relatively little injury was observed in the bark and cambium region of main limbs.

In the spring some new growth occurred on the pruned trees, but it was weak and many of the new leaves and shoots wilted and died. By midsummer it was apparent that several of the 8 pruned trees would not live and that there was little chance for the eventual recovery of the remaining trees. New growth on the unpruned trees was generally vigorous and in most cases a thick annual ring was laid down over the injured sapwood. Some twig dieback and crotch injury occurred on the unpruned trees (fig. 11), but they recovered from this hard freeze surprisingly well. Of course, the flower buds were all killed and no fruit was produced by any of these trees in 1957. Typical pruned and unpruned trees as they



Figure 11. Halehaven peach trees showing injury to twigs ("twig dieback") as a result of low temperature in January 1957, Ithaca, New York. New shoot growth has come from buds on uninjured wood at base of these twigs. (Photographed summer, 1957.)

appeared in midsummer are shown in figure 12.

Effect of chemical thinning on wood hardiness. Data have already been presented showing the effect of chemical thinning on subsequent cold hardiness of the flower buds (tables 4 and 5). In some of these freezing tests, duplicate twig samples were collected and frozen to determine the effect of the thinning treatments on cold hardiness of the twigs themselves. The results of two of these tests on twig hardiness are shown in tables 10 and 11. As the tables show, those thinning treatments that effectively reduced fruit set resulted in increased cold resistance in the twigs the following winter. The determination of in-

jury in the bark and wood of the frozen twigs was done by the electrical conductivity method as described earlier. When the twigs were frozen in the laboratory, the higher conductivity readings of samples from the unthinned trees indicated more extensive injury to the tissue.

Effect of fertilization and cultural treatments. Some determinations were made on cold hardiness of peach twigs from trees in the nitrogen fertilization and cultivation test conducted in Monroe County. The effect of the treatments on bud hardiness has already been discussed. The results of controlled-freezing tests on twigs collected during two seasons are presented in table 12. The twigs on



Figure 12. Halehaven trees in foreground were pruned in December, 1956, before a hard freeze in January. Trees in background were not pruned. (Photographed August, 1957.)

Table 10. Effect of chemical thinning on cold hardiness of Halehaven peach twigs, Niagara County, New York, 1950-51. (Twigs collected for freezing February 22, 1951)

Thinning treatment* (1950)	Blossoms setting fruit 7/21/50	Conductivity		
		Not frozen	Frozen at:	
			-10° F.	-12° F.
	Percent	Micromhos		
DN No. 1 $\frac{3}{4}$ lb./100 gal., May 12.....	12	90.5	108.2	114.1
NAA 30 p.p.m. June 20.....	13	90.9	94.6	116.0
Check.....	55	90.6	113.5	126.2

*DN No. 1 = Dinitro-O-cyclohexyl phenol.

NAA = Naphthaleneacetic acid.

trees receiving the heavier nitrogen applications were somewhat less hardy, as determined by these con-

trolled freezing tests, than twigs on similar trees receiving the moderate nitrogen fertilization. On the

Table 11. Effect of chemical thinning on cold hardiness of Elberta peach twigs, Wayne County, New York. 1954. (Twigs collected for freezing December 27, 1954)

Thinning treatment* (1954)	Blossoms setting fruit 7/20/54	Conductivity	
		Not frozen	Frozen at -14° F.
	Percent	Micromhos	
NPA 150 p.p.m. May 11.....	11.6	113.3	117.3
Cl-IPC 200 p.p.m. June 8.....	16.7	107.4	135.3
Check.....	33.3	114.6	142.3

*NPA = Naphthyl phthalamic acid.

Cl-IPC = 3Cl-Isopropyl -N- phenyl carbamate.

Table 12. Effect of cultural practice and nitrogen fertilization on cold hardiness of Elberta peach twigs, Monroe County, New York (Twigs collected for freezing December 14, 1949)

Temperature	Conductivity			
	LR*	LC*	HR*	HC*
	Micromhos			
Check (unfrozen).....	117.6	111.6	112.3	117.1
Frozen at -15° F.....	146.5	152.4	167.5	166.1

*See footnote * to table 6.

basis of these two tests, the nitrogen level had more influence on hardiness than did the cultural treatment. Observations on injury to the bark in crotches and on tree trunks from occasional low winter temperatures during this period indicated that these parts were also less hardy on the high-nitrogen trees, particularly if cultivation

was prolonged and no cover crop developed.

At present, a further appraisal is being made of the effect of nitrogen fertilization in relation to pruning severity on cold hardiness of peach trees as one phase of a larger study on orchard management practices for peaches.¹

Discussion

Development of hardiness in various tissues

Hardiness in plants may be defined as the ability to endure the hardship of an extreme environmental condition. Many plant

tissues that would be killed by exposure to a temperature only a few degrees below freezing when

¹Research project of the Pomology Department, New York State [Geneva] Agricultural Experiment Station.

in the active vegetative condition in the summer can develop cold resistance and endure very low temperatures in midwinter without injury. When a peach tree is actively growing, the new shoots and the new tissues of bark and sapwood contain a relatively high percentage of water. The cells and tissues of such a tree are tender and easily destroyed if the water in them freezes. Such ice formation probably brings about an irreversible change in the colloidal properties of the protoplasm.

As the period of vegetative growth and shoot extension begins to wane, the tree gradually increases its reserve of stored foods. The cell walls in the new tissues of the plant thicken and become more woody, the dry matter increases and the relative moisture content decreases. Thus, the plant prepares itself to resist the low temperatures that are to follow. Maximum resistance to cold in the winter thus depends to a large degree on whether the tree has been able to store an adequate supply of reserve foods for the proper maturity of the various tissues.

Any cultural or environmental condition that tends to prolong this vegetative condition in the tree through the summer delays the time at which the hardening processes will start. Such practices as heavy fertilization and continued clean cultivation during the summer tend to prolong this vegetative condition and delay hardening. Excessive rainfall and high temperatures in late summer will also delay the hardening processes. Moreover, cer-

tain processes necessary to the hardening of the tree are carried on only if the trees are gradually exposed to low temperatures in fall and early winter.

The first part of the tree in which this hardening process takes place in late summer and early fall is in the wood of the branches in the upper part of the tree. The flower buds also harden rapidly, as shown by the data on bud hardiness. The new shoots may develop cold resistance promptly if the tree is exposed to normal conditions of temperature and rainfall, and if the tree is not making late vegetative growth. The last tissue to harden is the bark on the main trunk, particularly near the ground, and in the main crotches.

In all these areas, the cambium is particularly slow to harden. The cambium cells divide during the growing season and lay down the new conducting tissues of phloem in the bark and xylem or sapwood on the inside. Since the cambium cells are dividing actively during the summer, especially if vegetative conditions are prolonged, it is logical that this tissue would be slow to harden in the fall. Thus, a sharp freeze in late fall will often damage only the least hardy but most vital part of the tree — the cambium and new conducting tissues of the trunk. The younger branches, flower buds, and even the twigs in the upper part of the tree may escape injury at this time of the year at a freezing temperature that kills the young tissues of the trunk and main limbs.

The serious aspect of this injury

is that with the cambium killed no new conducting tissues can be laid down over the dead tissues the following year. This prevents the movement of soil nutrients and water, absorbed by the roots, to the top of the tree during the following growing season to support continued growth. Thus, the tree dies even though it may have appeared normal in the spring as new shoot growth started. Even flowering and early fruit development may have taken place before the demands of the new growth exceeded the limited supply of stored food material in uninjured wood.

Assuming that no sharp freezes or abnormally low temperatures occur during the late fall and early winter, the cambium of healthy, normal trees goes on to develop considerable hardiness by mid-winter. Generally its hardiness at that time surpasses that of the sapwood, flower buds, and bark. Thus, low temperatures of mid-winter around -20°F . or lower may kill all the flower buds and cause extensive damage to the sapwood and bark but not injure the vital cells in the cambium tissues. With the advent of warm spring weather and the resumption of growth, the cambium will produce new conducting tissue over the injured sapwood and new phloem tissue in the inner bark to replace the damaged parts. Then, if favorable conditions prevail for a few weeks without excessively hot or dry weather, such a tree can recover. The older sapwood of the branches and trunk will be dead, a condition called "blackheart", but the tree

although somewhat more subject to breakage and deterioration, may still be able to survive and be productive for many years. Trees that have suffered injury to the vital tissues of the trunk from freezing temperatures in late fall may die or show extensive injury during the following season.

Orchard practices that contribute to maximum hardiness

It is apparent from the data and discussion presented in this bulletin that the severity and fluctuations of winter temperatures exert a profound influence on bud hardiness. The influence of any of the cultural practices studied was of minor degree.

In spite of the importance of fall and winter weather conditions, over which the grower has little control, proper management can mean the difference between loss of buds or wood injury and survival when a marginal temperature occurs. The management of the peach orchard should include early cultivation with cover cropping in late summer, or similar practices, to promote vigorous growth during spring and early summer, and to avoid late summer growth. This gives the new wood time to mature and harden before the subfreezing temperatures of late fall. Moderate fertilization will usually help to achieve this objective, and early flower or fruit thinning to prevent overbearing reduce the chance of winter injury to buds and wood. Moderate annual pruning is also necessary to maintain the tree in a vigorous, productive condition

but early winter pruning in areas where low winter temperatures are occasionally experienced should be avoided. Insect and disease control

is likewise essential if the trees are to be kept healthy and the leaves efficient for development of maximum hardiness.

Summary

Controlled freezing experiments have been carried on during the past 12 years in a study of the cold hardiness of peach flower buds and wood. This has been supplemented by observations and data taken after chance winter freezes that resulted in varying degrees of injury to trees in the test orchard.

The hardiness index, or temperature required to kill 50 percent of the flower buds, was determined from controlled-freezing data for Halehaven compiled during this period. For each season this index of bud hardiness was plotted with the daily mean temperatures to show the fluctuations in hardiness in relation to temperature trends.

The flower buds increase in hardiness rapidly with the cooler temperatures of the fall and early winter. Maximum hardiness for the winter occasionally coincided with the end of the rest period, which occurs about January 1 at Ithaca. During two winters, however, maximum hardiness was reached shortly before this date. Or it often occurred sometime after the first of January, associated with a period of continued cold temperature. In two years, 1946-47 and 1955-56, maximum hardiness was reached after the middle of February.

Fluctuations in the cold hardiness

were more frequent and extensive after the rest period ended early in January. The reason for this is that three or four days of mild temperature while the buds are in rest result in little if any loss in hardiness, but similar conditions *after* the rest period can cause appreciable loss in hardiness. Buds usually regained hardiness with succeeding periods of cold weather. This loss and gain of hardiness occurred periodically until the buds were advanced to the pink stage in the spring. In spite of the frequent periods when a warming trend during the winter caused loss in hardiness, a return to seasonal temperatures prevented extensive bud activity. Once the hardiness index for Halehaven dropped below -4°F . in late fall, it did not rise above this point until there was visible swelling of the buds in the early spring.

This fluctuation in hardiness while the buds were still dormant was of such magnitude that maximum hardiness developed during a prolonged cold period in January 1948, and 15 percent of the Halehaven buds survived -19°F . Two years later when above-normal temperatures prevailed during January, only moderate hardiness was attained and a temperature of -8°F .

in February killed about the same percentage of buds on these same trees.

The effect of several orchard practices on bud hardiness was investigated. A reduction in fruit set by the use of chemical thinning sprays increased bud hardiness the following winter.

Moderate differences in the level of nitrogen fertilization had little effect on peach bud hardiness. The effect of cultivation was compared with different cover-cropping practices and likewise no significant effects on bud hardiness were detected within the levels of tree vigor obtained in these tests.

Studies on cold hardiness of the woody tissues indicated much slower development of hardiness in the

wood than in the flower buds. It was usually not until early December that the twigs became more resistant to low temperature injury than the flower buds, but from that time on, the bark, cambium, and sapwood of twigs and main branches were generally more hardy than flower buds.

Chemical thinning was found to promote wood hardiness during the subsequent winter. A nitrogen status high enough to cause excessive vegetative growth in a tree also hindered development of hardiness, but of wood more than bud hardiness.

Early winter pruning had a marked effect on susceptibility to cold injury in both twigs and main branches.

Literature Cited

1. Bradford, F. C., and Cardinell, H. A.
1926. Eighty winters in Michigan orchards. Mich. Agr. Exp. Sta. Spec. Bul. 194.
2. Chaplin, C. E.
1948. Some artificial freezing tests of peach fruit buds. Amer. Soc. Hort. Sci. Proc. 52:121-129.
3. Dexter, S. T., Tottingham, W. E., and Graber, L. F.
1932. Investigations of the hardiness of plants by measurement of electrical conductivity. Pl. Physiol. 7:63, 78.
4. Edgerton, L. J.
1948. Peach fruit bud hardiness as affected by blossom thinning treatments. Amer. Soc. Hort. Sci. Proc. 52:112-114.
5. Edgerton, L. J.
1954. Fluctuations in the cold hardiness of peach flower buds during rest period and dormancy. Amer. Soc. Hort. Sci. Proc. 64:175-180.

6. Edgerton, L. J.
1953. Peach growing. N. Y. State Coll. Agr. Cornell Ext. Bul. 869: 1-39.
7. Edgerton, L. J., and Harris, R. W.
1950. Effect of nitrogen and cultural treatment on Elberta peach fruit bud hardiness. Amer. Soc. Hort. Sci. Proc. 55:51-55.
8. Edgerton, L. J., and Hoffman, M. B.
1952. The effect of thinning peaches with bloom and post-bloom sprays on the cold hardiness of the fruit buds. Amer. Soc. Hort. Sci. Proc. 60:155-159.
9. Edgerton, L. J., and Shaulis, N. J.
1953. The effect of time of pruning on cold hardiness of Concord grape canes. Amer. Soc. Hort. Sci. Proc. 62:209-213.
10. Harris, R. W., and Boynton, Damon
1952. Nitrogen fertilization and cultural practices in relation to growth and fruitfulness of an Elberta peach orchard in New York. Amer. Soc. Hort. Sci. Proc. 59:36-52.
11. Havis, Leon, and Lewis, I. P.
1938. Winter injury of fruit trees in Ohio. Ohio Agr. Exp. Sta. Bul. 596.
12. Hedrick, U. P.,
1917. The peaches of New York. N. Y. State Dept. Agr. Ann. Rept. 21, vol. 22:133-134.
13. Meader, E. M., Davidson, O. W., and Blake, M. A.
1945. A method for determining the relative cold hardiness of dormant peach fruit buds. Agr. Res. 70⁹:283-302.
14. Proebsting, E. L., Jr., and Fogle, Harold W.
1956. An apparatus and method of analysis for studying fruit bud hardiness. Amer. Soc. Hort. Sci. Proc. 68:6-14.
15. Scott, D. H., and Cullinan, F. P.
1946. Some factors affecting the survival of artificially frozen fruit buds of peach. J. Agr. Res. 73⁶:207-236.
16. Stuart, Neil W.
1938. Cold hardiness of some apple understocks and the reciprocal influence of stock and cion on hardiness. Amer. Soc. Hort. Sci. Proc. 35:387-389.

A publication of the
New York State College of Agriculture
a unit of the State University,
at Cornell University, Ithaca, New York

Received for publication February 1, 1960

